

# **A Global, High-resolution Gridded Product of Ecosystem Carbon and Water Fluxes (EC-MOD) Derived from FLUXNET Observations**

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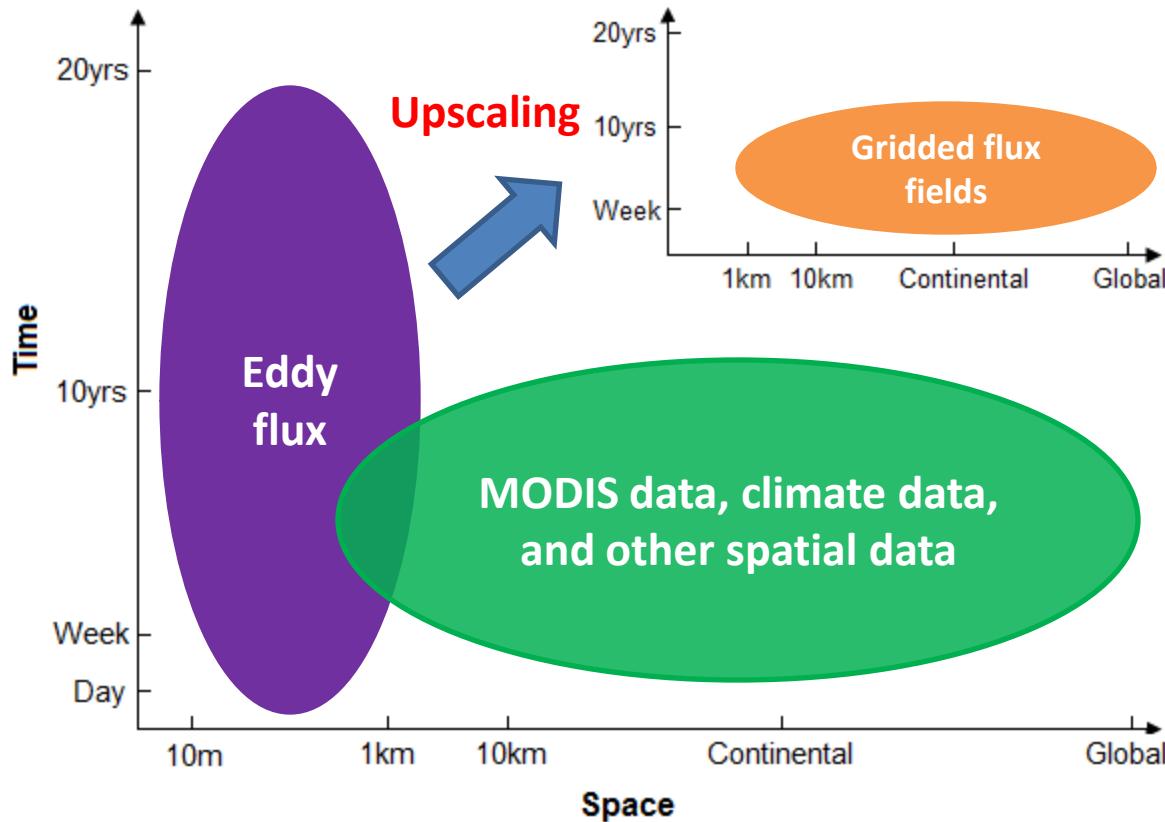
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# Main points

- To examine carbon and water cycling over regions, continents, or the globe, we need to upscale fluxes from towers to these broad regions (Xiao et al. 2008, Agri. For. Met.)
- At the global scale, however, the existing gridded flux fields derived from Fluxnet observations have coarse spatial resolution (0.5 degree)
- Recent studies have demonstrated that land cover heterogeneity and spatial resolution have significant effects on fluxes (e.g., Xiao et al. 2011, JGR)
- The development of a global, high-resolution product of ecosystem carbon and water fluxes is essential for capturing the effects of spatial heterogeneity on flux dynamics
- Here we use a data-driven approach (Xiao et al. 2008) to upscale carbon and water fluxes from towers to the global scale and develop a global, high-resolution (0.05 degree) gridded flux product (GPP, ER, NEE, and ET) over the period from 2000-2010
- We use our gridded flux fields to examine the magnitude, spatial patterns, and interannual variability of ecosystem carbon fluxes, ET, and water use efficiency
- Our EC-MOD flux fields will be useful for evaluating simulations of ecosystem models and atmospheric inversions over regions, continents, or the globe.

# Data and Methods

- FLUXNET data (Figure 1)
  - Carbon and water fluxes
  - PAR
  - Vegetation type
- MODIS data streams
  - Land cover map (MOD12C1)
  - Enhanced Vegetation Index (EVI) (MOD13C1)
  - Nadir BRDF-Adjusted Reflectance (MCD43C4)
  - Land Surface Temperature (LST) (MOD11C2)
- MERRA Reanalysis data
  - PAR



We use a data-driven approach (Xiao et al. 2008) to develop predictive GPP, Re, NEE, and ET models using site-specific flux data and MODIS data streams, and then apply the predictive models to the global scale to produce gridded flux estimates over the period 2000-2010.

**Xiao, J.** et al. (2008) Estimation of net ecosystem carbon exchange of the conterminous United States by combining MODIS and AmeriFlux data. *Agricultural and Forest Meteorology*, 148 (11), 1827-1847, doi:10.1016/j.agrformet.2008.06.015. [[PDF](#)]

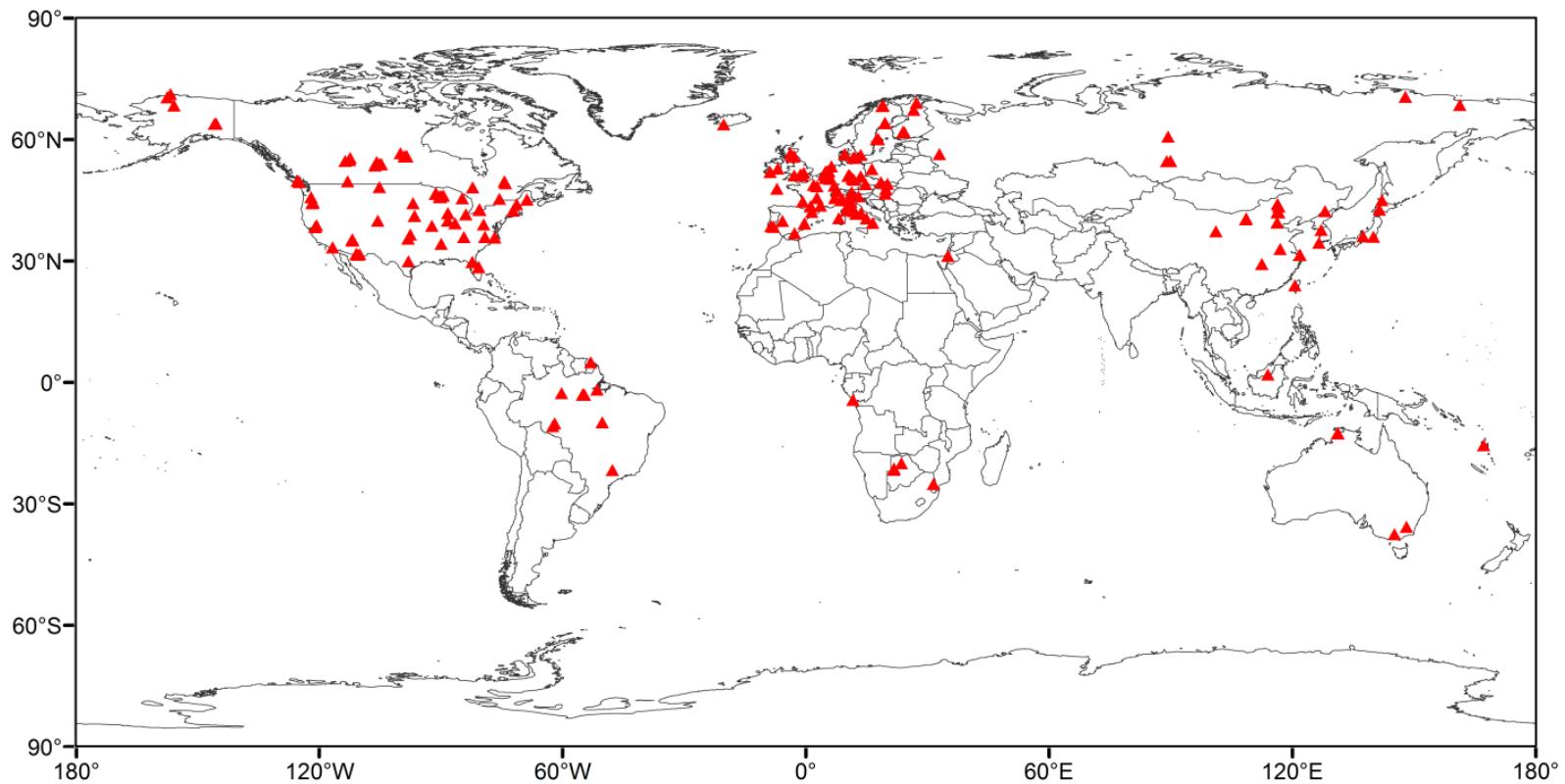


Figure 1. The location and distribution of FLUXNET sites involved in the LaThuile synthesis database.

Table 1. Annual fluxes for each broad vegetation type in each continent and over the globe: (a) GPP; (b) NEE; (c) ER; (d) ET.

(a) GPP (Pg C yr<sup>-1</sup>)

	<b>North America</b>	<b>Eurasia</b>	<b>South America</b>	<b>Africa</b>	<b>Oceania</b>	<b>Global</b>
Evergreen forests	4.52±0.08	12.69±0.31	22.19±0.65	7.74±0.26	2.29±0.09	49.80±1.33
Deciduous forests	0.92±0.02	1.31±0.04	0.47±0.03	0.16±0.00	0.00±0.00	2.86±0.04
Mixed forests	2.15±0.04	6.17±0.14	0.04±0.00	0.00±0.00	0.00±0.00	8.39±0.14
Shrublands	2.49±0.06	4.12±0.10	0.75±0.05	1.39±0.08	1.11±0.16	9.93±0.32
Savannas	1.31±0.03	2.53±0.08	7.79±0.33	13.89±0.62	1.15±0.10	26.69±1.06
Grasslands	1.09±0.08	2.85±0.09	1.12±0.09	1.09±0.06	0.08±0.01	6.24±0.16
Croplands	4.47±0.11	12.90±0.37	1.68±0.09	0.93±0.04	0.33±0.06	20.34±0.43
Total	16.96±0.30	42.58±0.80	34.04±1.14	25.20±0.95	4.96±0.34	124.25±2.86

(b) NEE (Pg C yr<sup>-1</sup>)

	<b>North America</b>	<b>Eurasia</b>	<b>South America</b>	<b>Africa</b>	<b>Oceania</b>	<b>Global</b>
Evergreen forests	-0.65±0.06	-1.67±0.16	-3.78±0.57	-1.10±0.11	-0.50±0.03	-7.75±0.79
Deciduous forests	-0.24±0.02	-0.43±0.03	-0.08±0.02	-0.03±0.00	0.00±0.00	-0.78±0.03
Mixed forests	-0.36±0.02	-0.93±0.05	-0.01±0.00	0.00±0.00	0.00±0.00	-1.30±0.06
Shrublands	-0.51±0.03	-0.83±0.05	-0.17±0.02	0.59±0.03	0.84±0.06	-0.09±0.12
Savannas	-0.12±0.01	-0.26±0.01	-0.31±0.12	-1.07±0.07	-0.06±0.02	-1.82±0.17
Grasslands	-0.02±0.03	-0.73±0.05	-0.04±0.02	0.71±0.03	0.004±0.003	-0.08±0.05
Croplands	-0.86±0.05	-1.81±0.15	-0.15±0.04	0.13±0.03	0.07±0.02	-2.62±0.17
Total	-2.77±0.14	-6.66±0.18	-4.54±0.70	-0.77±0.12	0.36±0.09	-14.44±0.81

(c) ER (Pg C yr<sup>-1</sup>)

	<b>North America</b>	<b>Eurasia</b>	<b>South America</b>	<b>Africa</b>	<b>Oceania</b>	<b>Global</b>
Evergreen forests	3.79±0.07	10.61±0.30	17.08±0.65	6.76±0.23	1.80±0.06	40.34±1.22
Deciduous forests	0.66±0.01	0.87±0.02	0.42±0.02	0.14±0.00	0.00±0.00	2.08±0.04
Mixed forests	1.64±0.02	4.75±0.11	0.04±0.00	0.00±0.00	0.00±0.00	6.45±0.12
Shrublands	1.42±0.05	2.36±0.06	0.47±0.03	1.41±0.07	1.18±0.14	6.90±0.26
Savannas	1.01±0.03	1.91±0.06	5.98±0.23	10.95±0.46	0.93±0.08	20.80±0.77
Grasslands	0.91±0.06	1.88±0.04	0.99±0.07	0.99±0.04	0.07±0.01	4.83±0.13
Croplands	3.16±0.07	10.57±0.27	1.46±0.06	0.95±0.03	0.34±0.04	16.50±0.36
Total	12.59±0.23	32.95±0.73	26.44±0.96	21.21±0.76	4.32±0.26	97.91±2.58

(d) ET (km<sup>3</sup> yr<sup>-1</sup>)

	<b>North America</b>	<b>Eurasia</b>	<b>South America</b>	<b>Africa</b>	<b>Oceania</b>	<b>Global</b>
Evergreen forests	1,805.7±29.3	4,800.9±117.8	8,483.9±273.1	3,225.5±106.9	825.6±34.4	19,268.0±533.0
Deciduous forests	339.5±12.7	526.2±19.0	267.8±15.3	82.0±2.4	0.17±0.01	1,217.0±28.2
Mixed forests	776.2±13.8	2,302.5±20.8	15.0±1.0	1.0±0.04	0.08±0.00	3,102.6±28.0
Shrublands	1,602.4±39.1	2,700.3±39.8	746.0±36.2	1,738.7±64.2	1,925.8±143.0	8,746.4±255.4
Savannas	695.1±11.6	1,294.3±32.0	4,274.6±153.0	8,415.6±292.4	738.8±45.2	15,435.6±482.9
Grasslands	819.1±39.0	1,946.3±34.9	653.9±37.2	1,072.5±27.1	54.4±5.3	4,548.3±84.4
Croplands	2,201.8±39.1	7,428.2±154.7	1,025.1±37.7	585.2±15.9	212.6±20.5	11,463.9±201.1
Total	8,239.8±141.1	20,999.1±331.0	15,466.2±534.6	15,120.5±487.9	3,757.6±219.6	63,781.9±1,477.0

Table 2. Comparison of global estimates of annual GPP and ET.

(a) GPP ( $\text{Pg C yr}^{-1}$ )

<b>Study</b>	<b>GPP</b>	<b>Period</b>	<b>Resolution</b>	<b>Method</b>
This study	124.3	2001-2010	5km	Data-driven
Zhao et al. (2006)	101.8-125.8	2000-2006	1km	LUE
Yuan et al. (2010)	110.5	2000-2003		LUE
Ryu et al. (*)	118	2001-2003	5km	Radiative transfer and modeling
Beer et al. (2010)	123		0.5 degree	Data-driven and modeling
Bonan et al. (2011)	130	1982-2004	1 degree	Land surface model
Welp et al. (2011)	150-175			

(b) ET ( $\times 10^3 \text{ km}^3 \text{ yr}^{-1}$ )

<b>Study</b>	<b>ET</b>	<b>Period</b>	<b>Resolution</b>	<b>Method</b>
This study	63.8	2001-2010	5km	Data-driven
Mu et al. (2011)	62.8	2000-2006	1km	LUE
Ryu et al. (*)	63.0	2001-2003	5km	
Jung et al. (2010)	65.0	1982-2008	0.5 degree	Data-driven
Oki and Kanae (2006)	65.5			
Trenberth et al. (2007)	72.6	1979-2000		

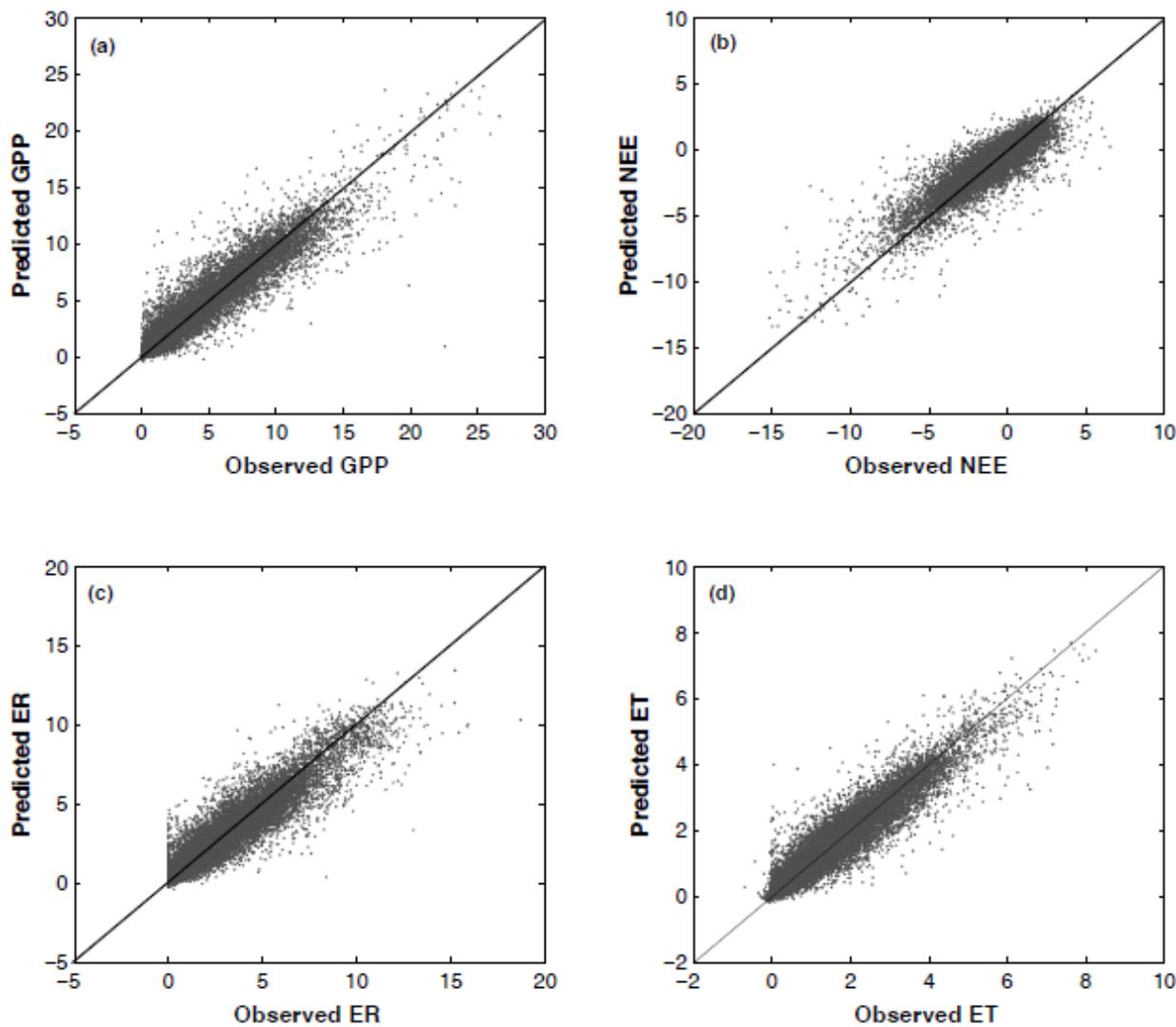


Figure 2. Cross-validation of the predictive models: (a) GPP ( $y = 0.89x + 0.41$ ,  $R^2 = 0.90$ ); (b) NEE ( $y = 0.78x - 0.16$ ,  $R^2 = 0.80$ ); (c) ER ( $y = 0.85x + 0.40$ ,  $R^2 = 0.86$ ); (d) ET ( $y = 0.90x + 0.15$ ,  $R^2 = 0.90$ ). The units of carbon fluxes are  $\text{g C m}^{-2} \text{ d}^{-1}$ , and the units of ET are  $\text{mm d}^{-1}$ .

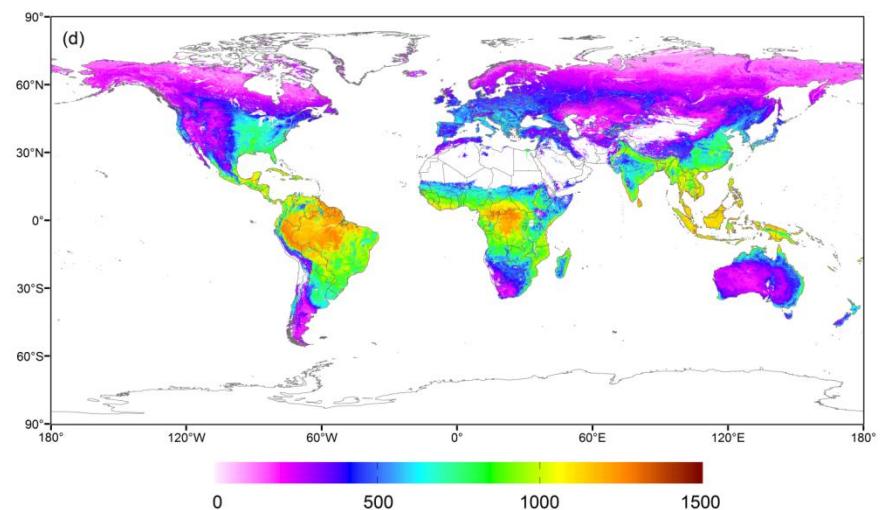
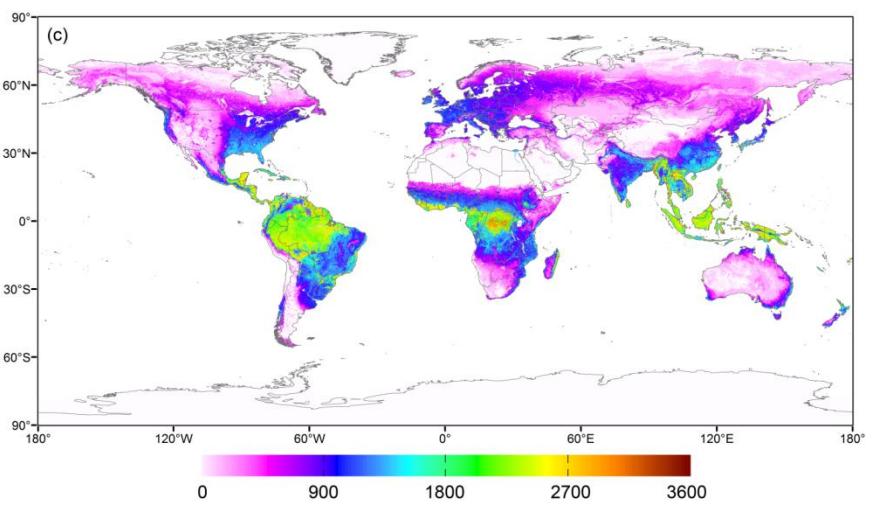
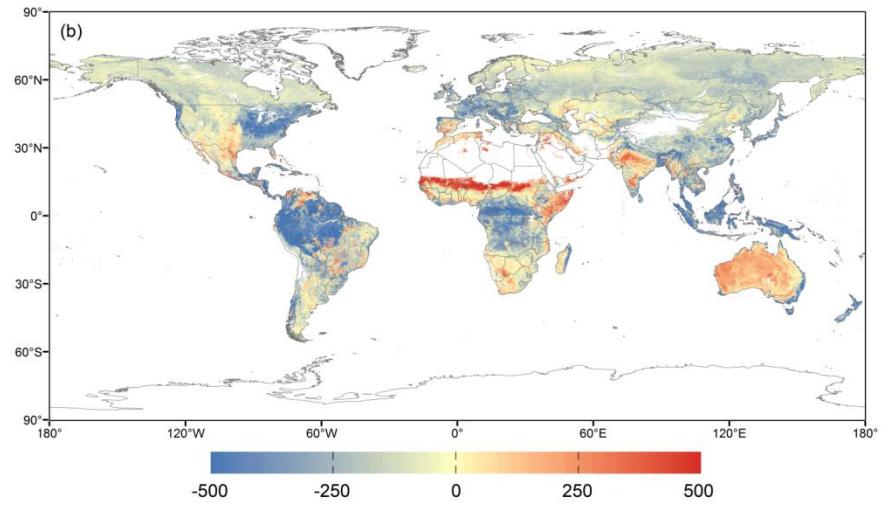
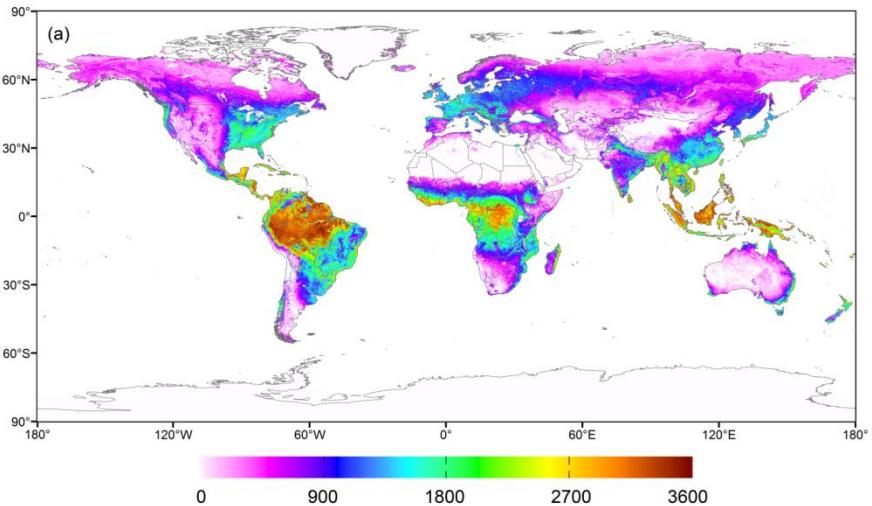


Figure 3. Mean annual fluxes over the period 2001-2010: (a) GPP; (b) NEE; (c) ER; (d) ET. The units of carbon fluxes are  $\text{g C m}^{-2} \text{yr}^{-1}$ , and the units of ET are  $\text{mm yr}^{-1}$ .

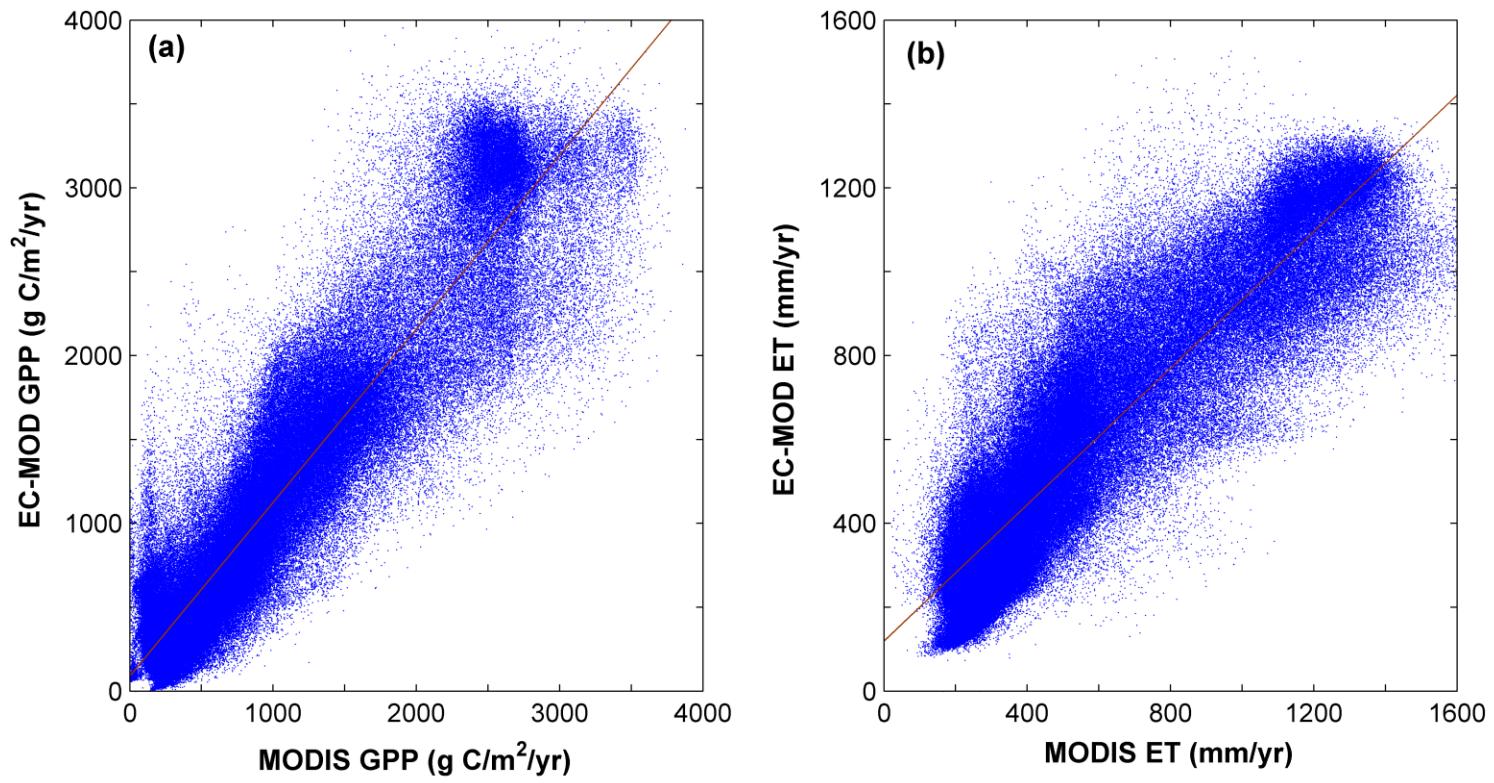


Figure 4. Comparison of global mean annual GPP and ET with annual fluxes from MODIS data products (Zhao et al. 2005; Mu et al. 2011): (a) GPP ( $y = 1.04x + 89.32$ ,  $R^2 = 0.86$ ); and (b) ET ( $y = 0.81x + 119.1$ ;  $R^2 = 0.81$ ).

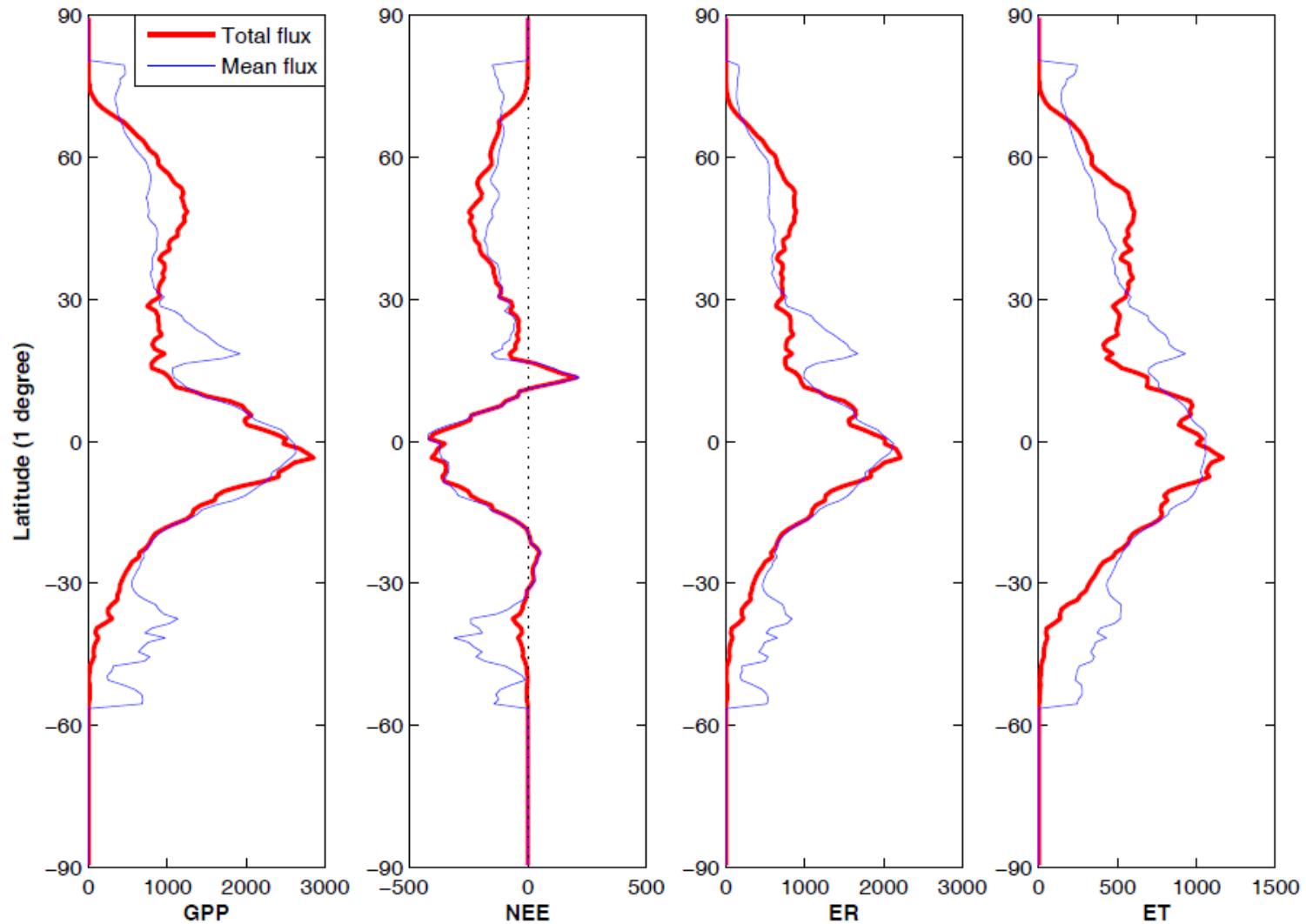


Figure 5. Longitudinal patterns of annual fluxes: (a) GPP; (b) NEE; (c) ER; (d) ET. For each variable, total flux (red, heavy solid line) is the flux integrated over each one-degree latitudinal band, and mean flux (blue solid line) is the average flux within each band. For carbon fluxes, the units for total and mean fluxes are  $\text{Tg C yr}^{-1}$  and  $\text{g C m}^{-2} \text{yr}^{-1}$ , respectively. For ET, the units of total and mean fluxes are  $\text{km}^3 \text{yr}^{-1}$  and  $\text{mm yr}^{-1}$ , respectively.

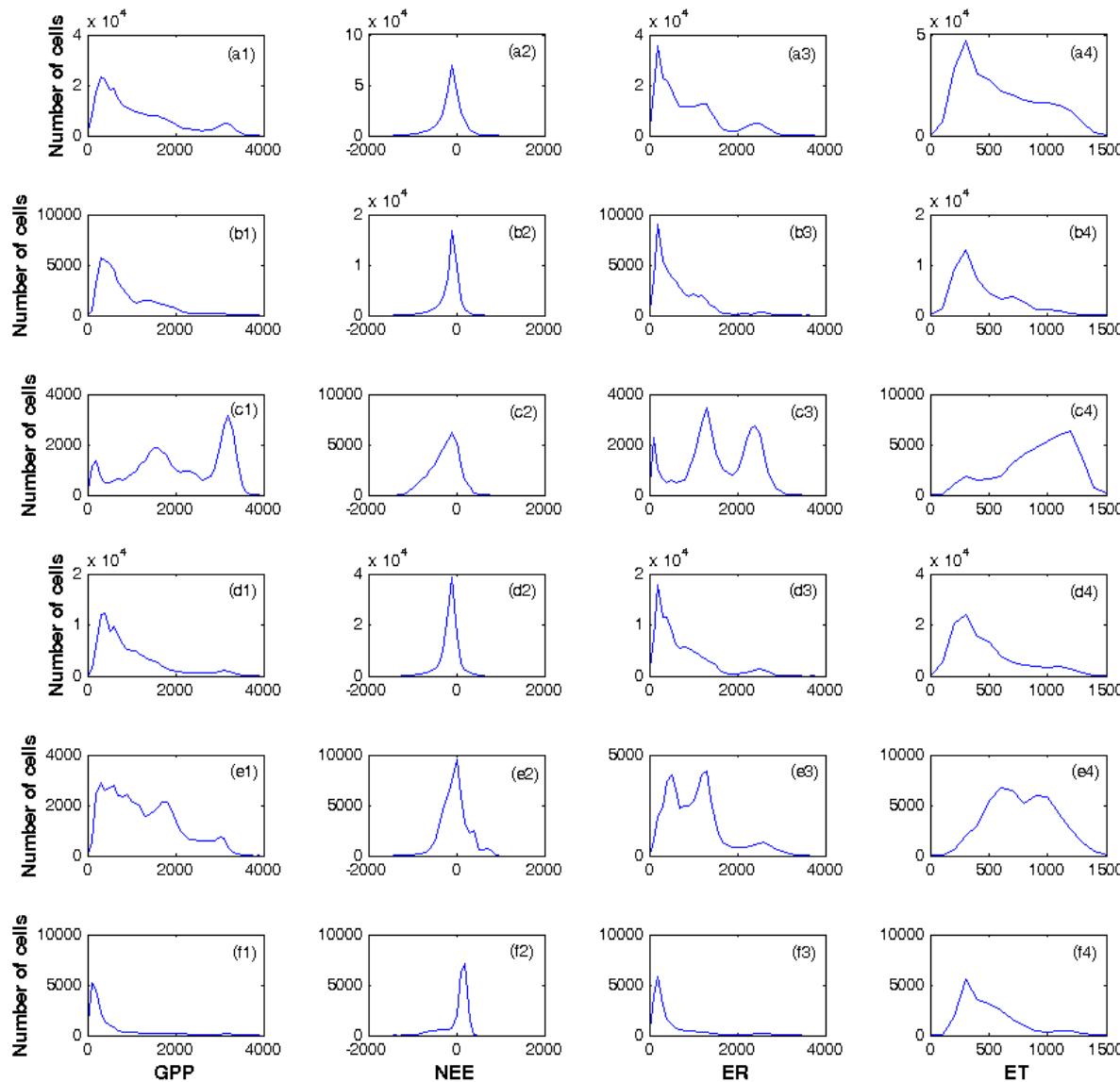


Figure 6. The frequency distribution of mean annual carbon and water fluxes for the globe and each continent. The rows of plots are (a) - globe, (b) - North America, (c) - South America, (d) - Eurasia, (e) - Africa, and (f) - Oceania, respectively, and the columns of plots are (1) - GPP, (2) –NEE, (3) - ER, and (4) - ET, respectively. The units of carbon fluxes are  $\text{g C m}^{-2} \text{ yr}^{-1}$ , and the units of ET are  $\text{mm yr}^{-1}$ .

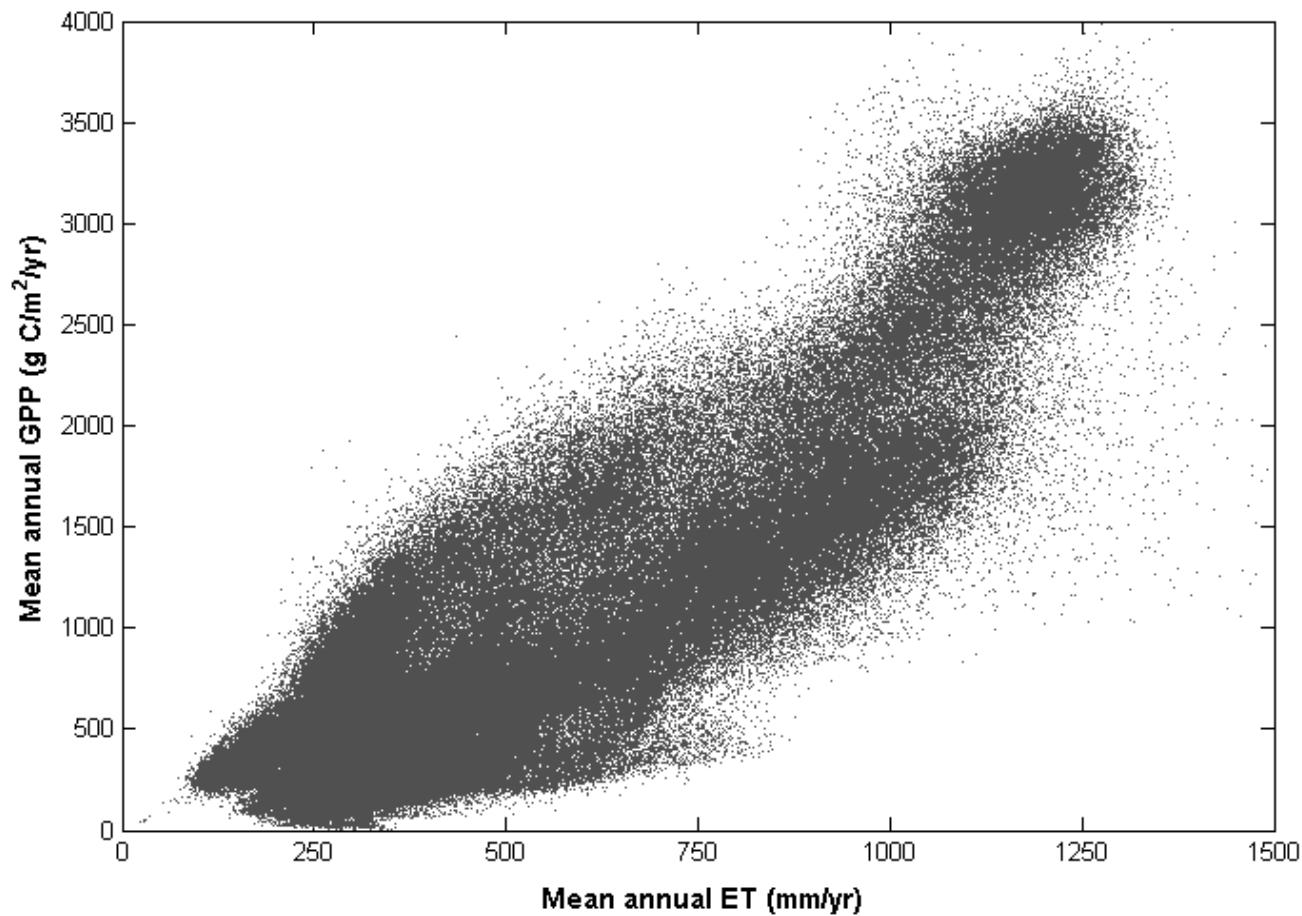


Figure 7. Relationship between mean annual ET and mean annual GPP.

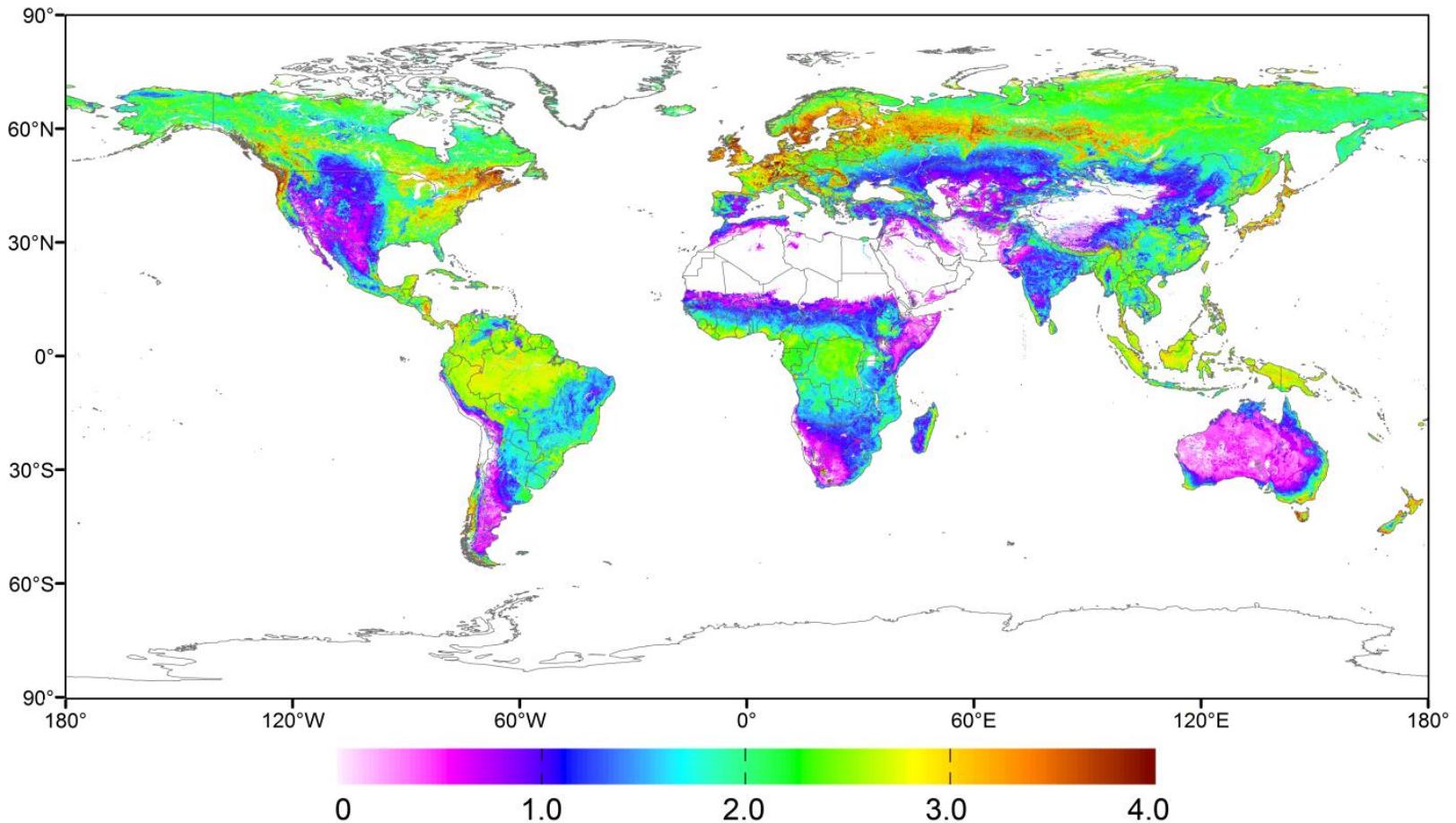


Figure 8. Mean annual water use efficiency over the period 2001-2010. The units are g C / kg H<sub>2</sub>O.

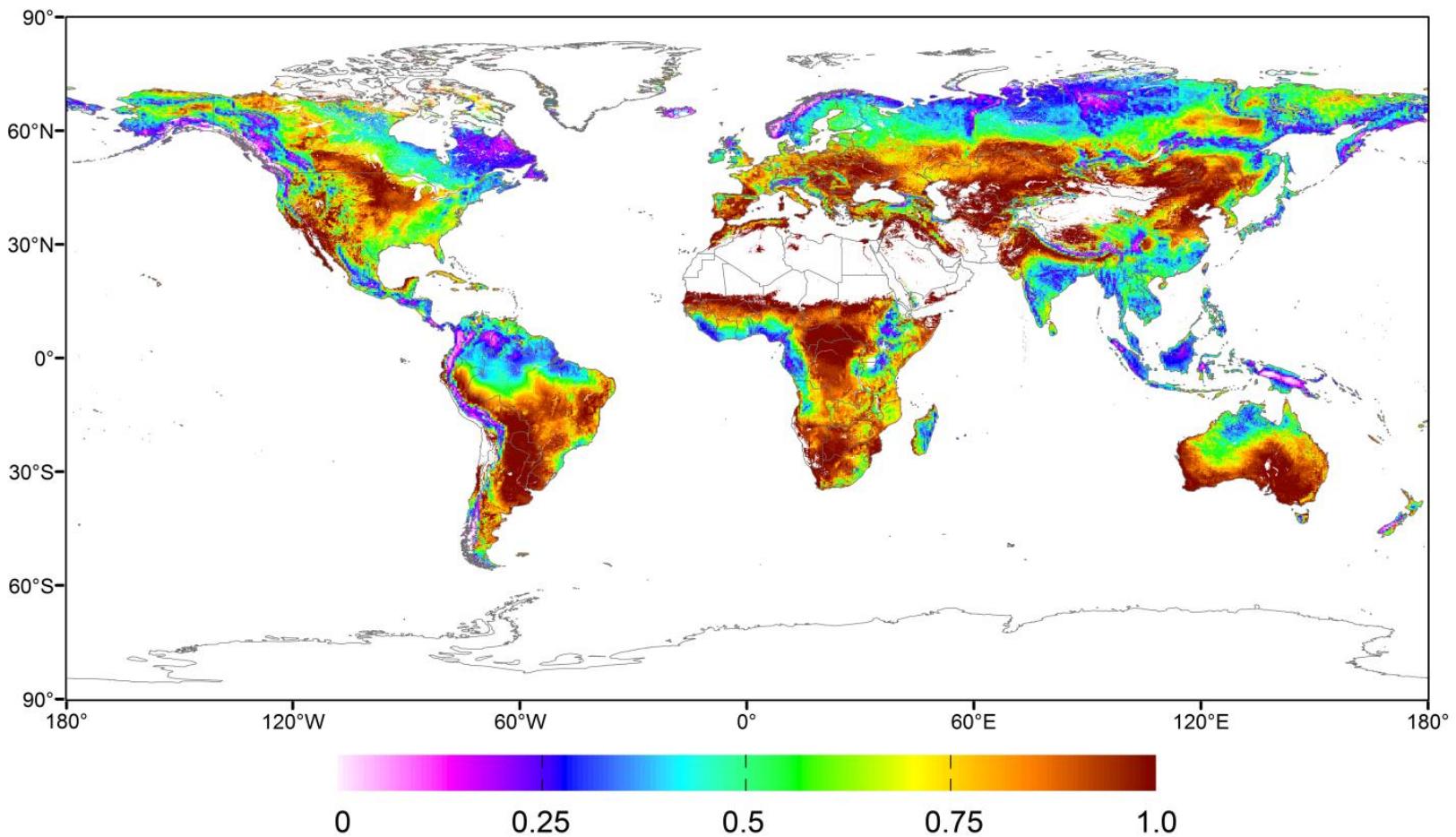


Figure 9. The ratio (ET/P) of mean annual evapotranspiration (ET, mm) to mean annual precipitation (P, mm).

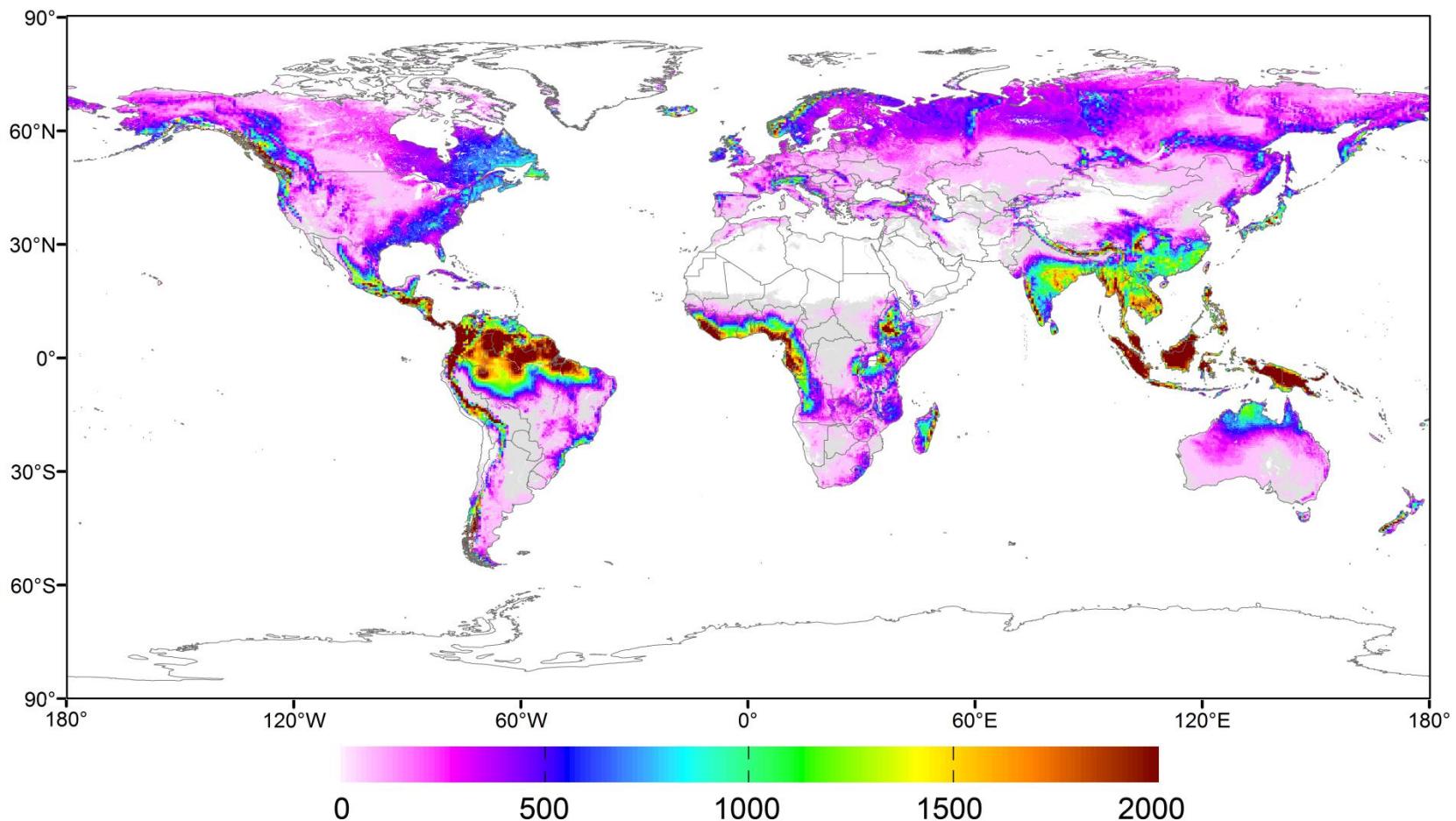


Figure 10. Mean annual water yield ( $P - ET$ ) over the period 2001–2010.  $P$  and  $ET$  are annual precipitation and evapotranspiration, respectively. The units are  $\text{mm yr}^{-1}$ . For gray cells,  $P$  is less than  $ET$ .